Chapter 2 - Hydrologic Analysis

The broad definition of hydrology is "the science which studies the source, properties, distribution, and laws of water as it moves through its closed cycle on the earth (the hydrologic cycle)." As applied in this manual, however, the term "hydrologic analysis" addresses and quantifies only a small portion of this cycle. That portion is the relatively short-term movement of water over the land resulting directly from precipitation and called surface water or stormwater runoff. Localized and long-term ground water movement must also be of concern, but generally only as this relates to the movement of water on or near the surface, such as stream base flow or infiltration systems.

The purpose of this chapter is to define the minimum computational standards required, to outline how these may be applied, and to reference where more complete details may be found, should they be needed. This chapter also provides details on the hydrologic design process; that is, what are the steps required in conducting a hydrologic analysis, including flow routing.

2.1   Minimum Computational Standards

The minimum computational standards depend on the type of information required and the size of the drainage area to be analyzed, as follows:

1.   For the purpose of designing <u>most types of </u>runoff treatment BMPs, a calibrated continuous simulation hydrologic model based on the EPA's HSPF (Hydrologic Simulation Program-Fortran) <u>must</u>~~should~~ be used to calculate runoff and determine the water quality design flow rates <u>and volumes</u>. ~~In the absence of a continuous model, the Soil Conservation Service (SCS) now Natural Resources Conservation Service (NRCS) Unit Hydrograph (SCSUH) method, or equivalent hydrograph techniques such as the Santa Barbara Urban Hydrograph (SBUH) method must be used to calculate runoff and determine the water quality design flow rates.~~

   For the purpose of designing ~~runoff treatment BMPs that are sized based upon the volume of runoff (~~wetpool treatment facilities~~)~~, <u>there are two acceptable methods: an approved continuous runoff model to estimate the 91st percentile, 24-hour runoff volume, or t</u>~~t~~he NRCS curve number method ~~should be used ~~to determine <u>a</u>~~the~~ water quality design storm <u>volume</u>. The water quality design storm <u>volume </u>is the <u>amount</u>~~volume~~ of runoff predicted from the 6-month, 24-hour storm.

   For the purpose of designing flow control BMPs, a calibrated continuous simulation hydrologic model, based on the EPA's HSPF, must be used ~~where available~~. ~~Where a calibrated~~

The circumstances under which different methodologies apply are summarized below.

Summary of the application design methodologies		
	BMP designs in western Washington	
Method	**Treatment**	**Flow Control**
SCSUH/SBUH	Method applies for BMPs that are sized based on the volume of runoff from a 6-month, 24-hour storm. Currently, that includes only wetpool-facilities.design 24-hr runoff volume in Volume 5. **Note**: These BMPs don't require generating a hydrograph.	Modified method applies where an approved continuous runoff model is not available. See Volume I, Minimum Requirement # 7: Flow Control, "Interim Guideline" Not Applicable
Continuous Runoff Models: (WWHM or approved alternatives. See below)	Method applies tofor all BMPs. that are sized based on the design runoff flow rates in Volume 5.	Method applies throughout Western Washingtonwhere available

2.   If a basin plan is being prepared, then athe hydrologic analysis shouldmust be performed using a continuous simulation model such as the EPA's HSPF model, the EPA's Stormwater Management Model (SWMM), or an equivalent model as approved by the local government.

Significant progress has been made in the development and availability of HSPF-based continuous runoff models for Western Washington. The Department of Ecology has coordinated the development of the Western Washington Hydrology Model (WWHM). It adjustsuses rainfall/runoff relationships developed for specific basins in the Puget Sound region to all parts of western Washington. Where field monitoring establishes basin-specific rainfall/runoff parameter calibrations, those can be entered into the model, superseding the default input parameters.

Two other HSPF-based continuous runoff models have been approved by the Department of Ecology: MGS Flood and KCRTS (King County Runoff Time Series). Though MGS Flood uses different, extended precipitation files, its features and more importantly, its runoff estimations are very similar to those predicted by WWHM. KCRTS is a

pre-packaged set of runoff files developed by King County. It can be used throughout King County. by the United States Geological Survey (in cooperation with the counties of King, Snohomish, Pierce, and Thurston) with the development of a local version of the HSPF model. This work has involved development of "runoff files" for various land types defined by vegetation, and soil type. These runoff files will describe runoff characteristics of simulated runoff from a watershed with measured runoff. As a result, one will be able to simulate runoff from any other ungauged basin where only the distribution of land types is known. The model will be able to be applied on individual development sites of less than about 200 acres.

A continuous simulation model has a considerable advantage over the single event-based methods such as the SCSUH, SBUH, or the Rational Method. The single event model cannot take into account storm events that may occur just before or just after the single event (the design storm) that is under consideration. In addition, the runoff files generated by the HSPF model are the result of a considerable effort to introduce local parameters and actual rainfall data into the model and are therefore believed to result in better estimation of runoff than the SCSUH, SBUH, or Rational methods. Where large master-planned developments are proposed, local governments should consider requiring a basin-specific calibration of HSPF rather than use of the default parameters in the above-referenced models. The Department of Ecology suggests such basin-specific calibrations should be considered for projects that will occupy more than 320 acres.

2.1.1 Discussion of Hydrologic Analysis Methods Used for Designing BMPs

This section provides a discussion of the methodologies to be used for calculating stormwater runoff from a project site. It includes a discussion of estimating stormwater runoff with single event models, such as the SBUH, versus continuous simulation models.

Single Event and Continuous Simulation Model

~~The use of single event hydrologic models has limitations when designing flow control BMPs and efforts are underway to make improved hydrologic analysis methods more widely available and used.~~ A continuous simulation model has considerable advantages over the single event-based methods such as the SCSUH, SBUH, or the Rational Method. HSPF is a continuous simulation model that is capable of simulating a wider range of hydrologic responses than the single event models such as the SBUH method. Single event models cannot take into account storm events that may occur just before or just after the single event (the design storm) that is under consideration. In addition, the runoff files generated by the HSPF models are the result of a considerable effort to introduce local parameters and actual rainfall data into the model and therefore produce better estimations of runoff than the SCSUH, SBUH, or Rational methods.

Ecology has developed a continuous simulation hydrologic model (WWHM) based on the HSPF for use in western Washington (see Section 2.2). Continuous rainfall records/data files have been obtained and appropriate adjustment factors were developed as input to HSPF. Input algorithms (referred to as IMPLND and PERLND) have been developed for a number of watershed basins in King, Pierce, Snohomish, and Thurston counties. These rainfall files and model algorithms are used in the HSPF in western Washington. Local counties and cities~~municipalities~~ ~~will be~~ are encouraged to develop basin-specific calibrations of HSPF that can be input into the WWHM.~~a continuous simulation model that is calibrated for their basins.~~ However, until such a calibration~~model~~ is developed for a specific basin, the input data mentioned above must be used throughout western Washington.

~~The SBUH model or a calibrated continuous simulation model based on HSPF may be used for designing runoff treatment BMPs. Please note, to meet Minimum Requirement #6 - Runoff Treatment - using the SBUH model, the water quality design storm specified in Volume I must be~~

~~treated. Where a continuous simulation model is available, the treatment BMPs must be sized using the appropriate design criteria specified for the BMPs in Volume 5. The discussion below will focus on the use of the SBUH method for estimating runoff and developing a runoff hydrograph.~~

~~The SBUH method, as recommended in the 1992 Manual, tends to overestimate runoff from predeveloped areas. In Volume I, certain changes to the SBUH parameters are recommended which are intended to result in more accurate estimates of runoff using SBUH. (See Minimum Requirement # 7: Flow Control, "Interim Guideline"). The suggested changes to the SBUH parameters are based on the runoff comparisons between the SBUH model and King County Runoff Time Series (KCRTS), an HSPF-based continuous simulation model.~~

Concerns with SBUH

A summary of the concerns with SBUH <u>and other single event models</u> is in order.

- While SBUH may give acceptable estimates of total runoff volumes, it tends to overestimate peak flow rates from pervious areas because it cannot adequately model subsurface flow (which is a dominant flow regime for pre-development conditions in western Washington basins). One reason SBUH overestimates the peak flow rate for pervious areas is that the actual time of concentration is typically greater than what is assumed. Better flow estimates could be made if a longer time of concentration was used. This would change both the peak flow rate (i.e., it would be lower) and the shape of the hydrograph (i.e., peak occurs somewhat later) such that the hydrograph would better reflect actual predeveloped conditions.

  - Another reason for overestimation of the runoff is the curve numbers (CN) in the 1992 Manual. These curve numbers were developed by US-Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS) and published as the Western Washington Supplemental Curve Numbers. These CN values are typically higher than the standard CN values published in Technical Release 55, June 1986. In 1995, the NRCS recalled the use of the western Washington CNs for floodplain

management and found that the standard CNs better describe the hydrologic conditions for rainfall events in western Washington. However, based on runoff comparisons with the KCRTS better estimates of runoff are obtained when using the western Washington CNs for the developed areas such as parks, lawns, and other landscaped areas. Accordingly, the CNs in this manual are changed to those in the Technical Release 55 except for the open spaces category for the developed areas which include, lawn, parks, golf courses, cemeteries, and landscaped areas. For these areas, the western Washington CNs are used. These changes are intended to provide better runoff estimates using the SBUH method.

The Another major weakness of the current use of SBUH is that it is used to model a 24-hour storm event, which is too short to model longer-term storms in western Washington. The use of a longer-term (e.g. 3- or 7-day storm) is perhaps better suited for western Washington.

Related to the last concern is the fact that single event approaches, such as SBUH, assume that flow control ponds are empty at the start of the design event. Continuous runoff models are able to simulate a continuous long-term record of runoff and soil moisture conditions. They simulate situations where ponds are not empty when another rain event begins.

Finally, single event models do not allow for estimation and analyses of flow durations nor water level fluctuations. Flow durations are necessary for discharges to streams. Estimates of water level fluctuations are necessary for discharges to wetlands and for tracking influent water elevations and bypass quantities to properly size treatment faclilitiesfacilities.

The SBUH model may not be adequate for modeling the hydrologic conditions in western Washington and therefore the use of a locally calibrated HSPF is recommended.

Treatment   When designing a runoff treatment BMP, SBUH or a calibrated continuous simulation hydrologic model based on HSPF may be used to develop the inflow hydrograph to the BMP. SBUH tends to underestimate

the time of concentration, thus the peak flow rate occurs too early. This would affect the treatment BMPs that are designed to achieve a specified residence time (designs are more conservative). Calculation of the residence time is sensitive to the shape of the inflow hydrograph. The inflow hydrograph is also of fundamental importance when designing an infiltration or filtration BMP as these BMPs are sized based on a routing of the inflow hydrograph through the BMP. The best solution at this time is to try to account for subsurface flow when estimating the time of concentration. For sites with low impervious cover, this will increase the time of concentration, thus reducing the peak flow rate and shifting the peak rate to a somewhat later time. Note that for BMPs which maintain "permanent pools" (e.g., wet ponds) none of the above concerns apply since the permanent pool volume is adequately predicted by SBUH.

Flow Control Where a continuous runoff model is not available, it is necessary to use a modified SBUH approach described in Volume I, Minimum Requirement # 7: Flow Control, "Interim Guideline". The modified SBUH approach approximates a design intended to achieve the flow duration standard by adjusting the target peak flow standard, restricting other variables, and applying volume correction factor. The volume correction factor in Figure

Figure 2.1   Volume Correction Factor to be Applied to Flow Control BMPs Based on Site Impervious Cover
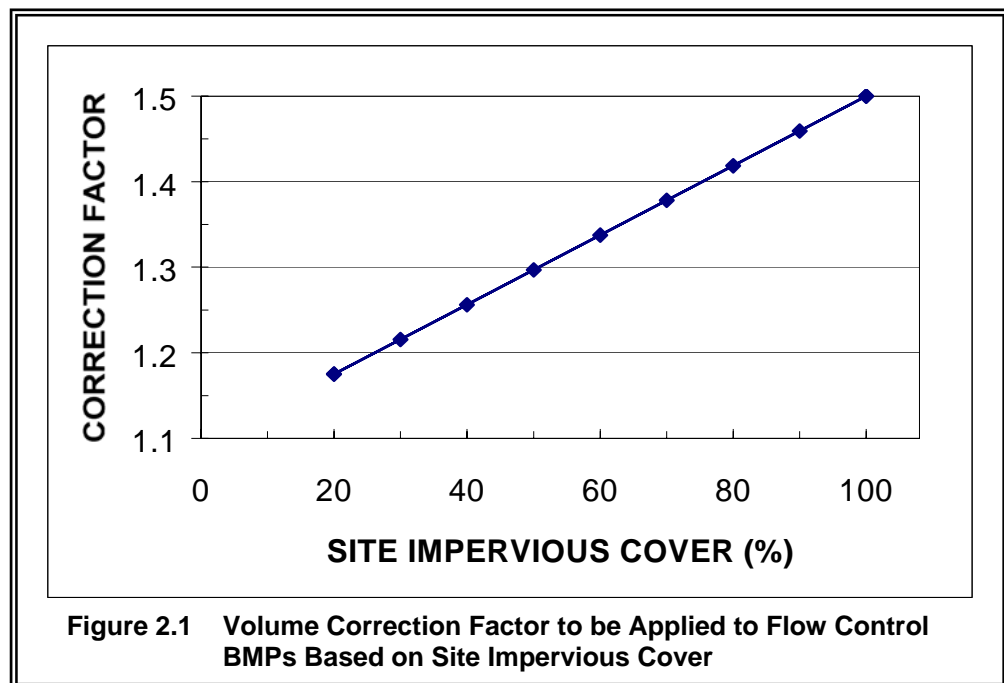
2.1 is based on the post development impervious cover and is necessary where the predeveloped condition is modeled as pasture. This correction factor is to be applied to the volume of the BMP without changing its depth or the design of the outlet structure, thus an increase in surface area will result.

Note that it is not necessary to apply the correction factor to the BMP volume for the runoff treatment storm.

Appendix III-A contains isopluvial maps for the 2, 10, and 100-year, 24-hour storm events, which are needed for matching the pre-development and post-development peak runoff associated with these storms.

Other precipitation frequency data may be obtained, for a fee, through Western Regional Climate Center (WRCC) at Tel: (775) 674-7010. WRCC can generate 1-30 day precipitation frequency data for the location of interest using data from 1948 to present (currently August 2000).

2.2 Western Washington Hydrology Model

This section summarizes the assumptions made in creating the western Washington Hydrology Model (WWHM) and discusses limitations of the model. More information on the WWHM and the assumptions can be found in Appendix III-B.

Limitations to the WWHM

The WWHM has been created for the specific purpose of sizing stormwater control facilities for new developments in western Washington. The WWHM can be used for a range of conditions and developments; however, certain limitations are inherent in this software. These limitations are described below.

The WWHM uses the EPA HSPF software program to do all of the rainfall-runoff and routing computations. Therefore, HSPF limitations are included in the WWHM. For example, backwater or tailwater control situations are not explicitly modeled by HSPF. This is also true in the WWHM.

In addition, the WWHM is limited in its routing capabilities. The user is allowed to input multiple a single stormwater control facilitiesyfacility and runoff is routed through themthis facility. If the proposed development site contains multiple facilities in series or involves routing through a natural lake, pond, or wetland in addition to multiple a stormwater control facilitiesyfacility then the user should use HSPF to do the routing computations and additional analysis. As of the publication date of this manual, certain model enhancements to the next version of WWHM are being planned that include adding the capability of routing through multiple facilities.

Routing effects become more important as the drainage area increases. For this reason it is recommended that the WWHM not be used for drainage areas greater than one-half square mile (320 acres). The WWHM can be used for small drainage areas less than an acre in size.

Assumptions made in creating the WWHM

Precipitation data.

- The WWHM uses long-term (43-50 years) precipitation data to simulate the potential impacts of land use development in western Washington. A minimum period of 20 years is required to simulate enough peak flow events to produce accurate flow frequency results.

- A total of 17 precipitation stations are used, representing the different rainfall regimes found in western Washington.

- These stations represent rainfall at elevations below 1500 feet - snowfall and snowmelt are not included in the WWHM.

- The primary source for precipitation data is National Weather Service stations.

- The computational time step used in the WWHM is one hour. The one-hour time step was selected to better represent the temporal variability of actual precipitation than daily data.

Precipitation multiplication factors.

- The WWHM uses precipitation multiplication factors to increase or decrease recorded precipitation data to better represent local rainfall conditions.

- The factors are based on the ratio of the 24-hour, 25-year rainfall intensities for the representative precipitation gage and the surrounding area represented by that gage's record.

- The factors have been placed in the WWHM database and linked to each county's map. They will be transparent to the general user, however the advanced user will have the ability to change the coefficient for a specific site. Changes made by the user will be recorded in the WWHM output. By default, WWHM does not allow the precipitation multiplication factor to go below 0.8 or above 2.

Pan evaporation data.

- The WWHM uses pan evaporation coefficients to compute the actual evapotranspiration potential (AET) for a site, based on the potential evapotranspiration (PET) and available moisture supply. AET accounts for the precipitation that returns to the atmosphere without becoming runoff.

- The pan evaporation coefficients have been placed in the WWHM database and linked to each county's map. They will be transparent to the general user. The advanced user will have the ability to change the

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coefficient for a specific site. These changes will be recorded in the WWHM output.

Soil data.

- The WWHM uses ~~with~~ three predominate soil type to represent the soils of western Washington: till, outwash, and saturated.

- The user determines actual local soil conditions for the specific development planned and inputs that data into the WWHM. The user inputs the number of acres of outwash (A/B), till (C/D), and saturated (~~D~~wetland) soils for the site conditions.

- Additional soils will be included in the WWHM if appropriate HSPF parameter values are found to represent other major soil groups.

Vegetation data.

- The WWHM will represent the vegetation of western Washington with three predominate vegetation categories: forest, pasture, and lawn (also known as grass).

- The ~~WWHM assumes that~~ predevelopment land conditions are generally assumed as forest (the default condition), however, ~~although~~ the user has the option of specifying pasture if there is documented evidence that pasture vegetation was native to the predevelopment site.

Development land use data.

- Development land use data are used to represent the type of development planned for the site and are used to determine the appropriate size of the required stormwater mitigation facility.

- ~~For the purposes of the WWHM developed land is divided into two major categories: standard residential and non-standard residential/commercial.~~

  - Among the land uses options, WWHM includes a Standard residential development which makes specific assumptions about the amount of impervious area per lot and its division between driveways and rooftops. Streets and sidewalk areas are input separately. Ecology has selected a standard impervious area of 4200 square feet per residential lot, with 1000 square feet of that as driveway, walkways, and patio area, and the remainder as rooftop area.

  - The WWHM distinguishes between effective impervious area and non-effective impervious area in calculating total impervious area.

  - Credits are given for infiltration and dispersion of roof runoff and for use of porous pavement for driveway areas. The WWHM2 currently includes an option for obtaining credits for the use of porous pavements on Streets/Sidewalk/Parking. The credit given under this option is believed to be too small. Until such time as WWHM2 is

upgraded to WWHM3, the LID credit guidance in Appendix C should be followed for porous pavements.

- For non-standard residential/commercial development the user inputs the roof area, landscape area, street, sidewalk, parking areas, and any appropriate non-developed forest and pasture areas.

- Forest and pasture vegetation areas are only appropriate for separate undeveloped parcels dedicated as open space, wetland buffer, or park within the total area of the development. ***Development areas must only be designated as forest or pasture where legal restrictions can be documented that protect these areas from future disturbances***.

- The WWHM provides options forcan model bypassing a portion of the runoff from the development area around a stormwater detention facility and/or having offsite inflow enter the development area.

Application of WWHM in Re-developments Projects

Redevelopment requirements may allow, for some portions of the redevelopment project area, the predeveloped condition to be modeled as the existing condition rather than forested or pasture condition. For the purposes of modeling using WWHM, project areas where flow mitigation is not required may be modeled as Offsite-Inflow.

Pervious and Impervious Land Categories (PERLND and IMPLND parameter values)

- In WWHM (and HSPF) pervious land categories are represented by PERLNDs; impervious land categories by IMPLNDs

- The WWHM provides 16 unique PERLND parameters that describe various hydrologic factors that influence runoff and 4 parameters to represent IMPLND.

- These values are based on regional parameter values developed by the U.S. Geological Survey for watersheds in western Washington (Dinicola, 1990) plus additional HSPF modeling work conducted by AQUA TERRA Consultants.

- Surface runoff and interflow will be computed based on the PERLND and IMPLND parameter values. Groundwater flow is not can also be computed and added to the total runoff from a development if there is a reason to believe that groundwater would be surfacing (such where there is a cut in a slope). However, the default condition in WWHM. It is assumesdassumed that very little or no groundwater flow from small catchments reaches the surface to become runoff. This is consistent with King County procedures (King County, 1998).

Guidance for flow control standards.

Flow control standards are used to determine whether or not a proposed stormwater facility will provide a sufficient level of mitigation for the additional runoff from land development.

There are two flow control standards stated in the Ecology Manual: Minimum Requirement #7 - Flow Control and Minimum Requirement #8 - Wetlands Protection (See Volume I). Minimum Requirement #7 specifies specific flow frequency and flow duration ranges for which the postdevelopment runoff cannot exceed predevelopment runoff. Minimum Requirement #8 specifies that discharges to wetlands must maintain the hydrologic conditions, hydrophytic vegetation, and substrate characteristics necessary to support existing and designated beneficial uses.

Minimum Requirement #7 specifies that stormwater discharges to streams shall match developed discharge durations to predeveloped durations for the range of predeveloped discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow. ~~In addition, the developed peak discharge rates should not exceed the predeveloped peak discharge rates for 2-, 10-, and 50-year return periods. In general, matching discharge durations between 50% of the 2-year and 50-year will result in matching the peak discharge rates in this range~~.

- The WWHM computes the predevelopment 2- through 100-year flow frequency values and computes the post-development runoff 2- through 100-year flow frequency values from the outlet of the proposed stormwater facility.

- The model uses pond discharge data to compare the predevelopment and postdevelopment ~~peak flows and~~ durations and determines if the flow control standards have been met.

- There are three criteria by which flow duration values are compared:

    1. If the postdevelopment flow duration values exceed any of the predevelopment flow levels between 50% and 100% of the 2-year predevelopment peak flow values (100 Percent Threshold) then the ~~Standard (1)~~ flow duration requirement has not been met.

    2. If the postdevelopment flow duration values exceed any of the predevelopment flow levels between 100% of the 2-year and 100% of the 50-year predevelopment peak flow values more than 10 percent of the time (110 Percent Threshold) then the ~~Standard (1)~~ flow duration requirement has not been met.

3. If more than 50 percent of the flow duration levels exceed the 100 percent threshold then the ~~Standard (1)~~ flow duration requirement has not been met.

Minimum Requirement #8 specifies that discharges to wetlands must maintain the hydrologic conditions, hydrophytic vegetation, and substrate characteristics necessary to support existing and designated beneficial uses. Criteria for determining maximum allowed exceedences in alterations to wetland hydroperiods are provided in guidelines cited in Guide Sheet 2B of the Puget Sound Wetland Guidelines (Azous and

Horner, 1997). Because wetland hydroperiod computations are relatively complex and are site specific they ~~will~~ have not yet been~~be~~ included in the WWHM2~~.~~ HSPF is required for wetland hydroperiod analysis. Ecology intends to include the ability to perform hydroperiod computations in WWHM3.

2.3 Single Event Hydrograph Method

Hydrograph analysis utilizes the standard plot of runoff flow versus time for a given design storm, thereby allowing the key characteristics of runoff such as peak, volume, and phasing to be considered in the design of drainage facilities. Because the only utility for single event methods in this manual is to size wet pool treatment facilities, only the subjects of design storms, curve numbers and calculating runoff volumes are presented.

The physical characteristics of the site and the design storm determine the magnitude, volume, and duration of the runoff hydrograph. Other factors such as the conveyance characteristics of channel or pipe, merging tributary flows, branching of channels, and flooding of lowlands can alter the shape and magnitude of the hydrograph. In the following sections, the key elements of hydrograph analysis are presented, namely:

Design storm hyetograph

Runoff parameters

Hydrograph synthesis

Hydrograph routing

Hydrograph summation and phasing

Computer applications

2.3.1 Water Quality Design Storm Hyetograph

All storm event hydrograph methods require the input of a rainfall distribution or design storm hyetograph. The design storm hyetograph is essentially a plot of rainfall depth versus time for a given design storm frequency and duration. It is usually presented as a dimensionless plot of unit rainfall depth (increment rainfall depth for each time interval divided by the total rainfall depth) versus time.

The hyetographs in Table 2.1 represent the rainfall distributions in Washington State. The hyetograph Type IA is the standard NRCS rainfall distribution as modified by King County and resolved to 10-minute time intervals for greater sensitivity in computing peak rates of runoff in urbanizing basins of western Washington. The hyetograph was interpolated from the NRCS mass distribution by Surface Water Management Division staff from King County. It may differ slightly from the distribution used in other NRCS-based computer models, particularly those that are not resolved to 10-minute time intervals. The hyetograph Type II is the standard NRCS rainfall distribution for eastern Washington. Figure 2.2 shows the 24-hr design storm hyetographs for the Types IA and II rainfall distributions.

The design storm hyetograph is constructed by multiplying the dimension-less hyetograph times the rainfall depth (in inches) for the design storm.

The design storm for sizing wetpool treatment facilities is the 6-month, 24-hour storm. Unless amended to reflect local precipitation statistics, the 6-month, 24-hour precipitation amount may be assumed to be 72 percent of the 2-year, 24-hour amount. Precipitation estimates of the 6-month and 2-year, 24-hour storms for certain towns and cities are listed in Appendix 1-B of Volume I. For other areas, interpolating between isopluvials for the 2-year, 24-hour precipitation and multiplying by 72% yields the appropriate storm size.

The total depth of rainfall (in tenths of an inch) for storms of 24-hour duration and 2, 5, 10, 25, 50, and 100-year recurrence intervals are published by the National Oceanic and Atmospheric Administration (NOAA). The information is presented in the form of "isopluvial" maps for each state. Isopluvial maps are maps where the contours represent total inches of rainfall for a specific duration. Isopluvial maps for the 2, 5, 10, 25, 50, and 100-year recurrence interval and 24-hour duration storm events can be found in the NOAA Atlas 2, "Precipitation - Frequency Atlas of the Western United States, Volume IX-Washington." Appendix II-A provides the isopluvials for the 2, 10, and 100-year, 24-hour design storms. Other precipitation frequency data may be obtained through Western Regional Climate Center (WRCC) at Tel: (775) 674-7010. WRCC can generate 1-30 day precipitation frequency data for the location of interest using data from 1948 to present (currently August 2000).

For project sites in western Washington with tributary drainage areas above elevation 1000 MSL, an additional total precipitation must be added to the total depth of rainfall, for the 25, 50, and 100-year design storm events, to account for the potential average snowmelt which occurs during major storm events.

This snowmelt factor (M_s) may be computed as follows:

This snowmelt factor (M_s) is

M_s (in inches) = 0.004 (MB_{el} - 1000);

where:

MB_{el} = the mean tributary basin elevation above sea level (in feet).

Example:

Given: Project location at an elevation of MB_{el} = 1837 feet.

Design Storm Event: 100-year P_{100} = 7 inches

Compute: $M_s = 0.004 (MB_{el} - 1000) = (0.004) (1837 - 1000)$
$= 3.35$ inches

Adjusted P_{100} $= P_{100} + M_s$
$= (7$ inches$) + (3.35$ inches$)$
$= 10.35$ inches

Table 2.1 24-Hour Design Storm Hyetograph Values - 10 minute Resolution		
Time (hour)	Type IA Rainfall Distribution	Type II Rainfall Distribution
0	0	0
0.166667	0.004	0.0017
0.333333	0.004	0.0016
0.5	0.004	0.0017
0.666667	0.004	0.0017
0.833333	0.004	0.0016
1	0.004	0.0017
1.166667	0.004	0.0017
1.333333	0.004	0.0016
1.5	0.004	0.0017
1.666667	0.004	0.0017
1.833333	0.005	0.0016
2	0.005	0.0017
2.166667	0.005	0.0017
2.333333	0.005	0.0016
2.5	0.005	0.0017
2.666667	0.005	0.0017
2.833333	0.006	0.0016
3	0.006	0.0017
3.166667	0.006	0.0033
3.333333	0.006	0.0034
3.5	0.006	0.0033

Table 2.1 24-Hour Design Storm Hyetograph Values - 10 minute Resolution		
Time (hour)	Type IA Rainfall Distribution	Type II Rainfall Distribution
3.666667	0.006	0.0033
3.833333	0.007	0.0034
4	0.007	0.0033
4.166667	0.007	0.0025
4.333333	0.007	0.0025
4.5	0.007	0.0025
4.666667	0.007	0.0025
4.833333	0.0082	0.0025
5	0.0082	0.0025
5.166667	0.0082	0.0025
5.333333	0.0082	0.0025
5.5	0.0082	0.0025
5.666667	0.0082	0.0025
5.833333	0.0095	0.0025
6	0.0095	0.0025
6.166667	0.0095	0.0042
6.333333	0.0095	0.0041
6.5	0.0095	0.0042
6.666667	0.0095	0.0042
6.833333	0.0134	0.0041
7	0.0134	0.0042

Time (hour)	Type IA Rainfall Distribution	Type II Rainfall Distribution
7.166667	0.0134	0.0033
7.333373	0.018	0.0034
7.5	0.018	0.0033
7.666667	0.034	0.0033
7.833333	0.054	0.0034
8	0.027	0.0033
8.166667	0.018	0.005
8.333333	0.0134	0.005
8.5	0.0134	0.005
8.666667	0.0134	0.005
8.833333	0.0088	0.005
9	0.0088	0.005
9.166667	0.0088	0.005
9.333333	0.0088	0.005
9.5	0.0088	0.005
9.666667	0.0088	0.005
9.833333	0.0088	0.005
10	0.0088	0.005
10.16667	0.0088	0.0083
10.33333	0.0088	0.0084
10.5	0.0088	0.0083
10.66667	0.0088	0.0117

Time (hour)	Type IA Rainfall Distribution	Type II Rainfall Distribution
10.83333	0.0072	0.0116
11	0.0072	0.0117
11.16667	0.0072	0.02
11.33333	0.0072	0.02
11.5	0.0072	0.055
11.66667	0.0072	0.1
11.83333	0.0072	0.19
12	0.0072	0.075
12.16667	0.0072	0.03
12.33333	0.0072	0.008
12.5	0.0072	0.008
12.66667	0.0072	0.008
12.83333	0.0057	0.008
13	0.0057	0.008
13.16667	0.0057	0.0083
13.33333	0.0057	0.0084
13.5	0.0057	0.0083
13.66667	0.0057	0.0083
13.83333	0.0057	0.0084
14	0.0057	0.0083

Table 2.1 (cont.)
24-Hour Design Storm Hyetograph Values - 10 minute Resolution

Time (hour)	Type IA Rainfall Distribution	Type II Rainfall Distribution
14.16667	0.0057	0.0058
14.33333	0.0057	0.0059
14.5	0.0057	0.0058
14.66667	0.0057	0.0058
14.83333	0.005	0.0059
15	0.005	0.0058
15.16667	0.005	0.0033
15.33333	0.005	0.0034
15.5	0.005	0.0033
15.66667	0.005	0.0033
15.83333	0.005	0.0034
16	0.005	0.0033
16.16667	0.005	0.0042
16.33333	0.005	0.0041
16.5	0.005	0.0042
16.66667	0.005	0.0042
16.83333	0.004	0.0041
17	0.004	0.0042
17.16667	0.004	0.0025
17.33333	0.004	0.0025
17.5	0.004	0.0025
17.66667	0.004	0.0025
17.83333	0.004	0.0025
18	0.004	0.0025

Time (hour)	Type IA Rainfall Distribution	Type II Rainfall Distribution
18.16667	0.004	0.0033
18.33333	0.004	0.0034
18.5	0.004	0.0033
18.66667	0.004	0.0033
18.83333	0.004	0.0034
19	0.004	0.0033
19.16667	0.004	0.0025
19.33333	0.004	0.0025
19.5	0.004	0.0025
19.66667	0.004	0.0025
19.83333	0.004	0.0025
20	0.004	0.0025
20.16667	0.004	0.0017
20.33333	0.004	0.0016
20.5	0.004	0.0017
20.66667	0.004	0.0017
20.83333	0.004	0.0016
21	0.004	0.0017
21.16667	0.004	0.0025

Table 2.1 (cont.)
24-Hour Design Storm Hyetograph Values - 10 minute Resolution

Time (hour)	Type IA Rainfall Distribution	Type II Rainfall Distribution
21.33333	0.004	0.0025

Table 2.1 (cont.) 24-Hour Design Storm Hyetograph Values - 10 minute Resolution		
Time (hour)	Type IA Rainfall Distribution	Type II Rainfall Distribution
21.5	0.004	0.0025
21.66667	0.004	0.0025
21.83333	0.004	0.0025
22	0.004	0.0025
22.16667	0.004	0.0017
22.33333	0.004	0.0016
22.5	0.004	0.0017
22.66667	0.004	0.0017
22.83333	0.004	0.0016
23	0.004	0.0017
23.16667	0.004	0.0017
23.33333	0.004	0.0016
23.5	0.004	0.0017
23.66667	0.004	0.0017
23.83333	0.004	0.0016
24	0.004	0.0017

Type IA Rainfall Distribution
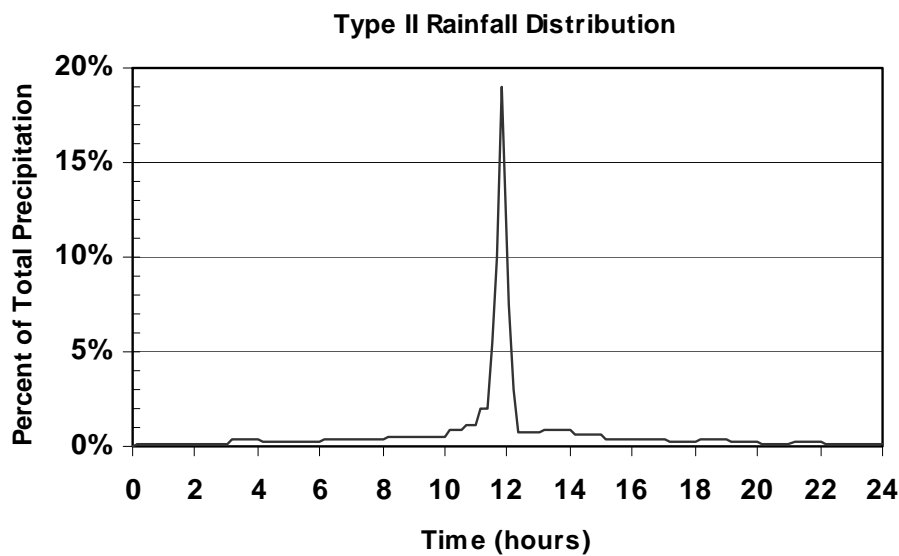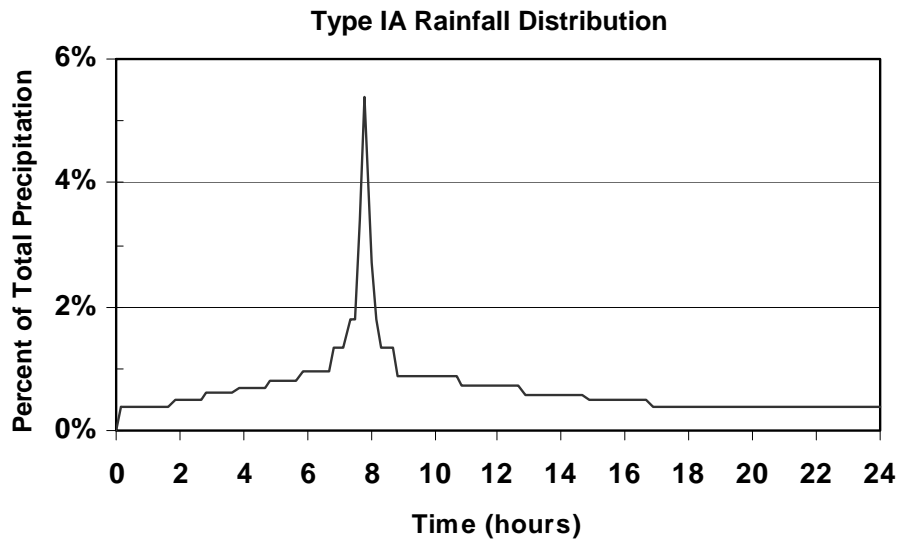

Type II Rainfall Distribution

Figure 2.2 24-hour Design Storm Hyetographs

2.3.2 Runoff Parameters

All storm event hydrograph methods require input of parameters that describe physical drainage basin characteristics. These parameters provide the basis from which the runoff hydrograph is developed. This section describes only the ~~three~~ key parameter~~s (area,~~ of curve number~~, and time of concentration)~~ that is used to estimate the runoff from the water quality design storm. ~~develop the hydrograph using the method of hydrograph synthesis discussed in Section 2.3.3~~.

Area   ~~The proper selection of homogeneous basin areas is required to obtain the highest degree of accuracy in hydrograph analysis. Significant differences in land use within a given drainage basin must be addressed by dividing the basin area into subbasin areas of similar land use and/or runoff characteristics. For example, a drainage basin consisting of a concentrated residential area and a large forested area should be divided into two subbasin areas accordingly. Hydrographs should then be computed for each subbasin area and summed to form the total runoff hydrograph for the basin.~~

~~To further enhance the accuracy of hydrograph analysis, all pervious and impervious areas within a given basin or subbasin must be analyzed separately, i.e., curve numbers and time of concentrations must be determined separately. This may be done by computing separate hydrographs for each area and combining them to form the total runoff hydrograph. This procedure is explained further in Section 2.3.3 "Hydrograph Synthesis." By analyzing pervious and impervious areas separately, the errors associated with averaging these areas are avoided and the true shape of the runoff hydrograph is better approximated.~~

Curve Number   The NRCS (formerly SCS) has, for many years, conducted studies of the runoff characteristics for various land types. After gathering and analyzing extensive data, NRCS has developed relationships between land use, soil type, vegetation cover, interception, infiltration, surface storage, and runoff. The relationships have been characterized by a single runoff coefficient called a "curve number." The National Engineering Handbook - Section 4: Hydrology (NEH-4, SCS, August 1972) contains a detailed description of the development and use of the curve number method.

NRCS has developed "curve number" (CN) values based on soil type and land use. They can be found in "Urban Hydrology for Small Watersheds", Technical Release 55 (TR-55), June 1986, published by the NRCS. The combination of these two factors is called the "soil-cover complex." The soil-cover complexes have been assigned to one of four hydrologic soil groups, according to their runoff characteristics. NRCS has classified over 4,000 soil types into these four soil groups. Table 2.2 shows the hydrologic soil group of most soils in the state of Washington and provides a brief description of the four groups. For details on other soil types refer to the NRCS publication mentioned above (TR-55, 1986).

Table 2.2 Hydrologic Soil Series for Selected Soils in Washington State			
Soil Type	**Hydrologic Soil Group**	**Soil Type**	**Hydrologic Soil Group**
Agnew	C	Hoko	C
Ahl	B	Hoodsport	C
Aits	C	Hoogdal	C
Alderwood	C	Hoypus	A
Arents, Alderwood	B	Huel	A
Arents, Everett	B	Indianola	A
Ashoe	B	Jonas	B
Baldhill	B	Jumpe	B
Barneston	C	Kalaloch	C
Baumgard	B	Kapowsin	C/D
Beausite	B	Katula	C
Belfast	C	Kilchis	C
Bellingham	D	Kitsap	C
Bellingham variant	C	Klaus	C
Boistfort	B	Klone	B
Bow	D	Lates	C
Briscot	D	Lebam	B
Buckley	C	Lummi	D
Bunker	B	Lynnwood	A
Cagey	C	Lystair	B
Carlsborg	A	Mal	C
Casey	D	Manley	B
Cassolary	C	Mashel	B
Cathcart	B	Maytown	C
Centralia	B	McKenna	D
Chehalis	B	McMurray	D
Chesaw	A	Melbourne	B
Cinebar	B	Menzel	B
Clallam	C	Mixed Alluvial	variable
Clayton	B	Molson	B
Coastal beaches	variable	Mukilteo	C/D
Colter	C	Naff	B
Custer	D	Nargar	A
Custer, Drained	C	National	B
Dabob	C	Neilton	A
Delphi	D	Newberg	B
Dick	A	Nisqually	B
Dimal	D	Nooksack	C
Dupont	D	Norma	C/D
Earlmont	C	Ogarty	C
Edgewick	C	Olete	C
Eld	B	Olomount	C
Elwell	B	Olympic	B
Esquatzel	B	Orcas	D
Everett	A	Oridia	D
Everson	D	Orting	D
Galvin	D	Oso	C
Getchell	A	Ovall	C
Giles	B	Pastik	C
Godfrey	D	Pheeney	C
Greenwater	A	Phelan	D
Grove	C	Pilchuck	C
Harstine	C	Potchub	C
Hartnit	C	Poulsbo	C
Hoh	B	Prather	C

Table 2.2 Hydrologic Soil Series for Selected Soils in Washington State (cont)			
Soil Type	**Hydrologic Soil Group**	**Soil Type**	**Hydrologic Soil Group**
Puget	D	Solleks	C
Puyallup	B	Spana	D
Queets	B	Spanaway	A/B
Quilcene	C	Springdale	B
Ragnar	B	Sulsavar	B
Rainier	C	Sultan	C
Raught	B	Sultan variant	B
Reed	D	Sumas	C
Reed, Drained or Protected	C	Swantown	D
Renton	D	Tacoma	D
Republic	B	Tanwax	D
Riverwash	variable	Tanwax, Drained	C
Rober	C	Tealwhit	D
Salal	C	Tenino	C
Salkum	B	Tisch	D
Sammamish	D	Tokul	C
San Juan	A	Townsend	C
Scamman	D	Triton	D
Schneider	B	Tukwila	D
Seattle	D	Tukey	C
Sekiu	D	Urbana	C
Semiahmoo	D	Vailton	B
Shalcar	D	Verlot	C
Shano	B	Wapato	D
Shelton	C	Warden	B
Si	C	Whidbey	C
Sinclair	C	Wilkeson	B
Skipopa	D	Winston	A
Skykomish	B	Woodinville	B
Snahopish	B	Yelm	C
Snohomish	D	Zynbar	B
Solduc	B		

Notes:

Hydrologic Soil Group Classifications, as Defined by the Soil Conservation Service:

A = *(Low runoff potential) Soils having low runoff potential and high infiltration rates, even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (greater than 0.30 in/hr.).*

B = *(Moderately low runoff potential). Soils having moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.3 in/hr.).*

C = *(Moderately high runoff potential). Soils having low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine textures. These soils have a low rate of water transmission (0.05-0.15 in/hr.).*

D = *(High runoff potential). Soils having high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a hardpan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr.).*

* = *From SCS, TR-55, Second Edition, June 1986, Exhibit A-1. Revisions made from SCS, Soil Interpretation Record, Form #5, September 1988 and various county soil surveys.*

Table 2.3 shows the CNs, by land use description, for the four hydrologic soil groups. These numbers are for a 24-hour duration storm and typical antecedent soil moisture condition preceding 24-hour storms.

The following are important criteria/considerations for selection of CN values:

Many factors may affect the CN value for a given land use. For example, the movement of heavy equipment over bare ground may compact the soil so that it has a lesser infiltration rate and greater runoff potential than would be indicated by strict application of the CN value to developed site conditions.

CN values can be area weighted when they apply to pervious areas of similar CNs (within 20 CN points). However, high CN areas should not be combined with low CN areas. In this case, separate ~~hydrographs~~ estimates of S and Qd should be generated and summed to obtain the cumulative runoff volume~~form one hydrograph~~ unless the low CN areas are less than 15 percent of the subbasin.

Separate CN values must be selected for the pervious and impervious areas of an urban basin or subbasin. For residential districts the percent impervious area given in Table 2.3 must be used to compute the respective pervious and impervious areas. For proposed commercial areas, planned unit developments, etc., the percent impervious area must be computed from the site plan. For all other land uses the percent impervious area must be estimated from best available aerial topography and/or field reconnaissance. The pervious area CN value must be a weighted average of all the pervious area CNs within the subbasin. The impervious area CN value shall be 98.

~~For storm duration other than 24 hours, an adjustment must be made to the CN values given in Table 2.3. Based on information obtained from SCS, the following equation shall be used for adjusting these CNs for the seven-day design storm:~~

~~CN (7 day) = 0.1549 CN + 0.8451 [(CN$^{2.365}$/631.8) + 15)]~~

Example: The following is an example of how CN values are selected for a sample project.

Select CNs for the following development:

Existing Land Use	-	forest (undisturbed)
Future Land Use	-	residential plat (3.6 DU/GA)
Basin Size	-	60 acres
Soil Type	-	80 percent Alderwood, 20 percent Ragnor

Figure 2.14 illustrates how a development with standard on-site detention can cause an increase in peak flow at some point downstream. If this is the case, the local government shall require that this condition be addressed by reducing the release rate from the detention facility such that the cumulative effect downstream is negligible as shown in Figure 2.15.
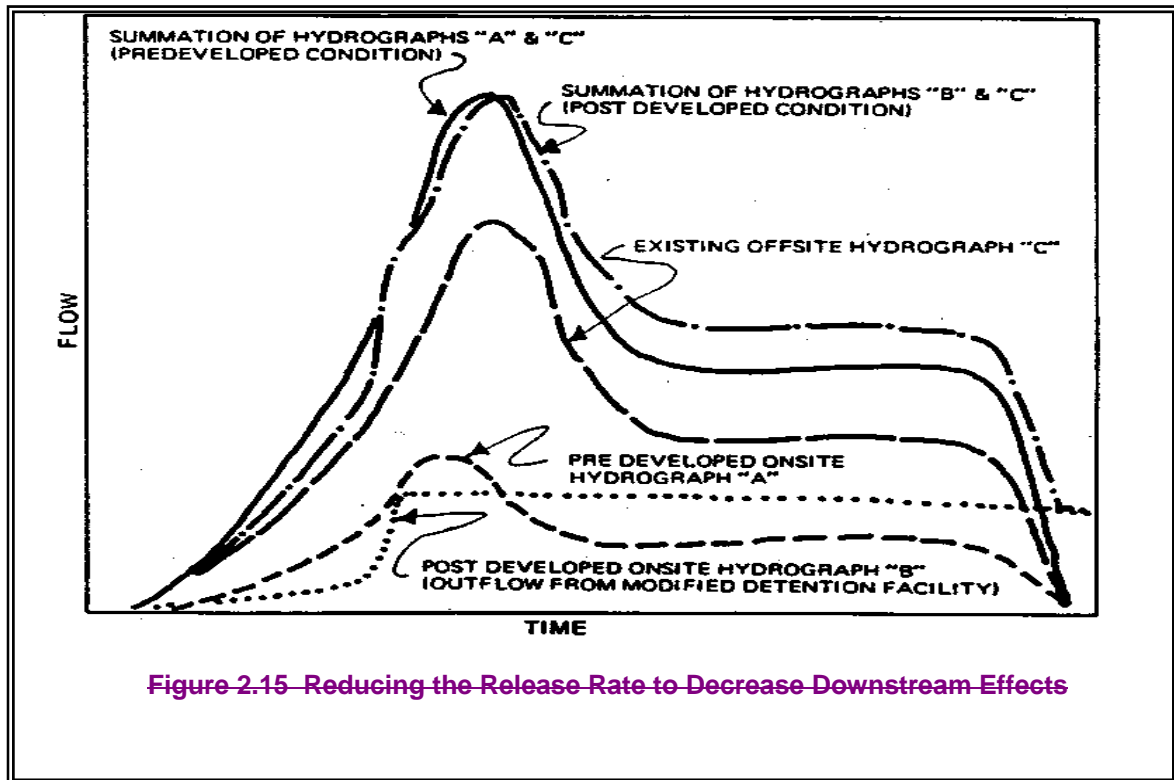

Figure 2.15 Reducing the Release Rate to Decrease Downstream Effects

2.3.6 Computer Applications

SBUH Method and Level Pool Routing: The computations required to generate the runoff hydrographs and perform the level pool routing techniques presented in this chapter can be performed manually. However, due to the number of computations and repetitive nature, a programmable calculator and/or a personal computer will perform these computations much quicker and with a likely higher degree of accuracy. There are also commercial programs available that perform these calculations.

Computer Models: Local governments may make available programs and application templates developed in-house. These will likely be available on a "make-your-own-copy basis" and will be provided with minimal documentation and no formal support. Software developers have prepared programs that they market and support. Local governments may maintain a list of these programs as they approve them for use.

2.4   Closed Depression Analysis

The analysis of closed depressions requires careful assessment of the existing hydrologic performance in order to evaluate the impacts a proposed project will have. The applicable requirements, (see Minimum Requirement #7) and the local government's Sensitive Areas Ordinance and Rules (if applicable) should be thoroughly reviewed prior to proceeding with the analysis.

Closed depressions generally facilitate infiltration of runoff. If a closed depression is classified as a wetland, then the Minimum Requirement #8 for wetlands applies. If there is an outflow from this wetland to a surface water (such as a creek), then the flow from this wetland must also meet the Minimum Requirement #7 for flow control. A calibrated continuous simulation hydrologic model must be used for closed depression analysis and design of mitigation facilities. If a closed depression is not classified as a wetland, model the ponding area at the bottom of the closed depression as an infiltration pond using WWHM.

Where an adequately calibrated continuous simulation model is not available, the procedures below may be followed.

Analysis and Design Criteria: The infiltration rates used in the analysis of closed depressions must be determined according to the procedures in Section 3.3. For closed depressions containing standing water, soil texture tests must be performed on dry land adjacent to, and on opposite sides of the standing water (as is feasible). The elevation of the testing surface at the bottom of the test pit must be one foot above the standing water elevation. A minimum of four tests must be performed to prepare an average surface infiltration rate.

Projects proposing to modify or compensate for replacement storage in a closed depression must meet the design criteria for detention ponds as described in this volume.

Method of Analysis: Closed depressions are analyzed using hydrographs routed as described in Section 2.3.4 "Hydrograph Routing." Infiltration must be addressed where appropriate. In assessing the impacts of a proposed project on the performance of a closed depression there are three cases that dictate different approaches to meeting Minimum Requirement #7 and applicable local requirements. Note that where there is a flooding potential, concern about rising ground water levels, or there are local sensitive area ordinances and rules, this analysis may not be sufficient and the local governments may require more stringent analysis.